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Numerical Taxonomy of the Genus *Pidonia* Mulsant from Korea (Coleoptera, Cerambycidae)

Seung Lak AN[1] and Yong Jung KWON[2]

[1] Department of Natural History, National Science Museum, Taejon 305-338, Korea
[2] Department of Agricultural Biology, College of Agriculture,
Kyungpook National University, Taegu 702-701, Korea

Abstract A numerical classification is attempted to show how much the result by cluster analysis with traditional taxonomic views on the Korean *Pidonia*. To determine the effect on the phenetic systematics of different suites of characters, and to assess the effect of the 6 different clustering methods and each 3-4 measures of them, a total of 87 phenetic characters covering 260 character states were used here. With the inclusion of genitalic characters the most acceptable classifications were derived from the analysis.

Key words Numerical taxonomy, phenetics, Coleoptera, Cerambycidae, *Pidonia*, Korea

INTRODUCTUION

One of the difficulties in dealing with the taxonomy of the genus *Pidonia* is that, in general appearance, the group is very homogeneous and frequently several sympatric species are found in each collecting site. The external morphological similarity, which associated with a high diversity in species, makes also a serious difficulty in the recognition of species in this genus. To solve them, the general practices using the proportions or measurements from external strucures and relying mostly on characters of the male genitalia are made. However, no method of multiple character analysis containing the simultaneous use of either qualitative or quantitative characters has ever been attempted. In this article, mathematical methods are first applied to know how much the placement of species in the genus by the cluster analysis accords with the traditional views based on external structures of genitalia. The second aim is to compare the effects on numerical classifications with different suites of characters, e.g. male genitalia against external characters. And to assess the effects of several other taxonomic procedures, some clustering methods joined with different measures, including or excluding 'NC'(no comparison) values, and similarity or dissimilarity coefficients were used.

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MATERIALS & METHODS

Computation was carried out using SPSS/PC+ (Version: 2.0), installed in microcomputers (expert 386, with Intel 80387 coprocessor), and SPSS-X (Version: 2.0) installed in the mainframe computer (Cyber 170-815) in the Computer Center of Kyungpook National University. Lotus 123, Minitab, PE 3, Statgraphics and the other software packages such as FORTRAN 77 programs were additionally used for the data processing.

Thirteen operational taxonomic units (OTU's) for all known species of the genus *Pidonia* in Korea were treated in these analyses (Table 1).

Table 1. List of OTU's(operational taxonomic unit) used.

OTU	Species	OTU	Species
1	*Pidonia (Mumon) debilis*	8	*Pidonia (Pidonia) koreana*
2	*Pidonia (Omphalodera) puziloi*	9	*Pidonia (Pidonia) weolseoae*
3	*Pidonia (Pidonia) alpina*	10	*Pidonia (Pidonia) longipennis*
4	*Pidonia (Pidonia) alticollis*	11	*Pidonia (Pidonia) seungmoi*
5	*Pidonia (Pidonia) amurensis*	12	*Pidonia (Pidonia) similis*
6	*Pidonia (Pidonia) elegans*	13	*Pidonia (Pidonia) suvorovi*
7	*Pidonia (Pidonia) gibbicollis*		

A sum of 87 basic phenetic characters covering 260 character states, either quantitative or qualitative, two-state or multi-state, ordered or unordered, were selected(Fig. 1, Table 2).

Data processing based on similarity or dissimilarity for each OTU was carried out through suits of FORTRAN, SPSS/PC+ and SPSS-X. The FORTRAN program read an input multi-state data matrix and recorded this matrix to the output binary data matrix, and another output binary data matrix which included 'no comparison' code to prevent comparison of unavailable particular characters (cf. Dunn & Everitt, 1982).

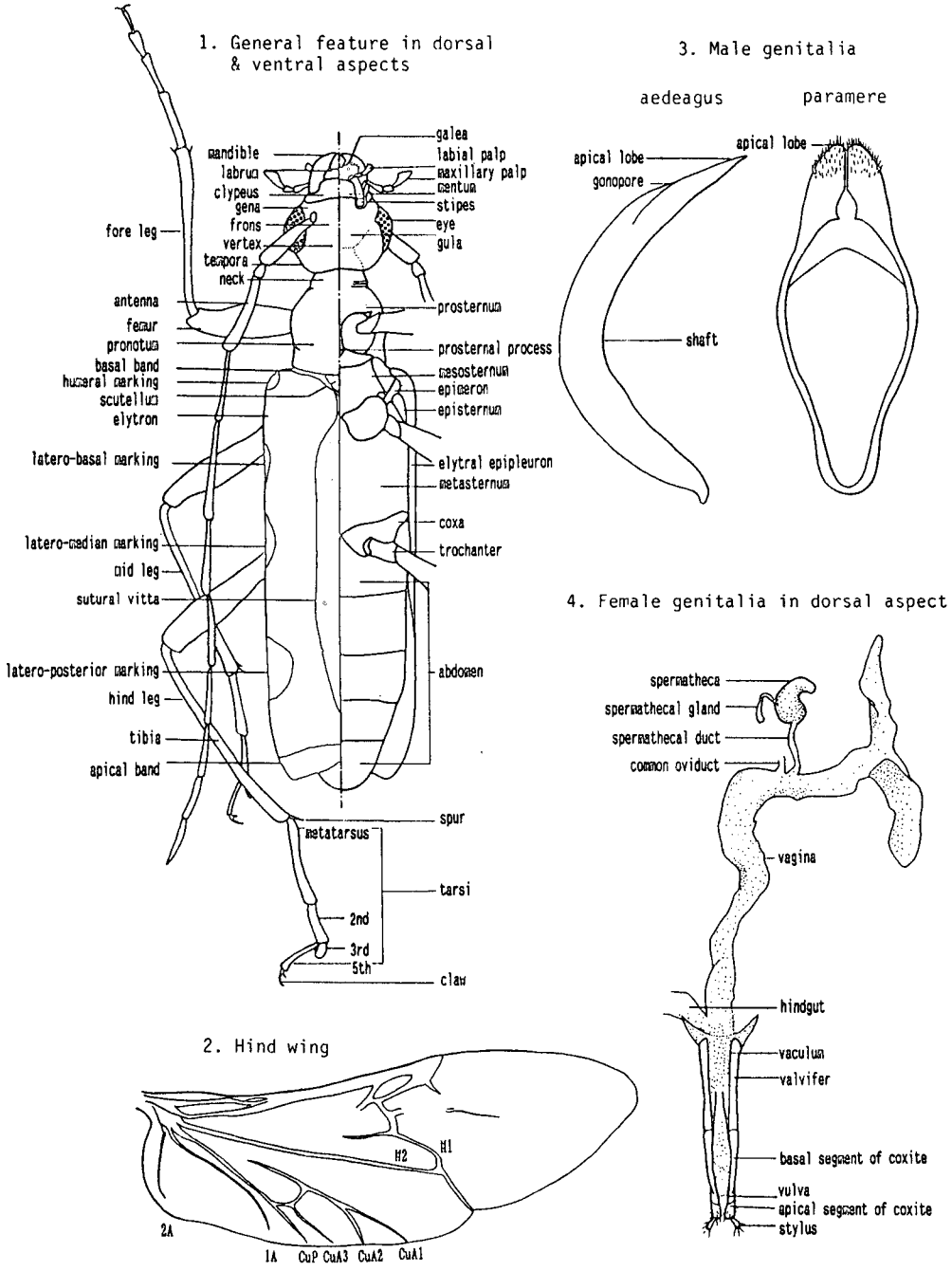

Fig. 1. Generalized morphological terminology in the genus *Pidonia*.

Table 2. List of characters and coded character states: two-state and multi-state, ordered or unordered variables.

(General)

1. Color of male: (1) black, (2) dark brown with marking, (3) yellowish brown with marking, (4) dark brown without marking.
2. Ditto, female: (1) black, (2) dark brown with marking, (3) yellowish brown with marking, (4) light without marking.
3. Size of male: (1) small (<7mm), (2) intermediate(7-10mm), (3) large(>10mm).
4. Ditto, female: (1) small (<7mm), (2) intermediate (7-10mm), (3) large (>10.5mm).
5. Appearance of male (length/width): (1) robust (<3.5), (2) medium (3.5−4), (3) elongate(>4).
6. Ditto, female (length/width): (1) robust(<3.4), (2) medium (3.4-3.7), (3) elongate (>3.7).

(Head)

7. Color of head: (1) light, (2) yellowish brown with 2 black stripes, (3) largely black, (4) entirely black.
8. Male, width of head to basal prothorax: (1) broader (>1.1), (2) intermediate (0.95-1.1), (3) narrower (<0.95).
9. Female ditto: (1) broader (>1.1), (2) intermediate (1.1-0.98), (3) narrower (<0.98).
10. Female, color of frontoclypeus: (1) bicolor, (2) light, (3) variable (light or bicolor).
11. Male labrum (width/length): (1) broad (>1.6), (2) narrow (<1.6).
12. Male, apical segment of maxillary palpus with outer margin: (1) produced, (2) not produced.
13. Ditto, with apical margin: (1) produced, (2) not produced.
14. Disc of vertex: (1) flat, (2) slightly convex.
15. Median longitudinal furrow on vertex: (1) extending forward to neck, (2) not so.
16. Inner margin of eye: (1) scarcely emarginate, (2) strikingly emarginate.
17. Tempora: (1) gradually narrowed posteriorly, (2) subparallel at basal half, (3) subparallel at basal 1/3.
18. Male, antennal length (up to 10th segments) to elytral apex: (1) surpassing, (2) reaching, (3) not reaching.
19. Female, ditto: (1) surpassing, (2) reaching, (3) not reaching.
20. Male, 2nd antennal segment (length/width): (1) long (>1), (2) short (<1).
21. Male, length of 3rd antennal segment to 1st and 2nd combined: (1) longer (>1), (2) intermediate (1-0.8), (3) shorter (<0.8).
22. Male, 6th antennal segment to 7th: (1) longer, (2) shorter.
23. Male, color of antennae: (1) yellowish brown, with 3rd and succeeding segments dark apically, (2) yellowish brown, with 5th and succeeding segments dark apically, (3) yellowish brown throughout.

(Thorax)

24. Male, color of pronotum: (1) with dark red patches apically and basally, (2) yellowish brown, (3) dark to black, (4) entirely black, (5) orange with lateral black stripes.
25. Female, ditto: (1) black with dark red patches apically and basally, (2) dark reddish brown, (3) yellowish brown, (4) entirely black, (5) orange with lateral black stripes.
26. Color of sternum: (1) black, (2) black with brownish patch, (3) reddish or yellowish brown.
27. Male, pronotum (length/broadest width): (1) longer, (2) not so.
28. Female, ditto: (1) longer, (2) not so.
29. Lateral tubercle of pronotum (length to basal width): (1) broad, (2) not so.
30. Ditto, position: (1) bafore middle, (2) middle.
31. Ditto, shape in dorsal aspect: (1) round, (2) angulate.
32. Height of pronotum (maximum height/height of anterior margin): (1) high (>1.9), (2) low (<1.9)
33. Male, median longitudinal keel on pronotum: (1) absent, (2) present, (3) variable (absent or present).
34. Female, ditto: (1) absent, (2) present.
35. Scutellum (length/basal width): (1) longer, (2) not so.
36. Ditto, apex: (1) bluntly pointed, (2) subroundly truncate.

37. Ditto, pubescence: (1) dense, (2) sparse.
38. Ditto, color: (1) black, (2) dark red, (3) yellowish brown, (4) reddish brown.

(Elytron)

39. Male, color: (1) yellowish brown, (2) black, (3) variable.
40. Female, ditto: (1) yellowish brown, (2) black, or black with yellowish brown stripes, (3) variable.
41. Basal band: (1) absent, (2) interrupt to humeral marking, (3) continuous to humeral marking.
42. Sutural vitta: (1) absent, (2) narrowed indistinctly, (3) fused with latero-posterior marking, (4) broadened basally, (5) narrowed basally and continuous to basal band.
43. Humeral marking: (1) absent, (2) variable (present or absent), (3) fused with latero-basal marking.
44. Latero-basal marking: (1) absent, (2) fused with latero-median marking, (3) independent, round, (4) independent, elongate.
45. Latero-median marking: (1) absent, (2) fused with latero-apical marking, (3) independent, round, (4) independent, elongate.
46. Latero-apical marking: (1) absent, (2) fused with apical marking, (3) independent, but continuous to latero-median marking, (4) entirely independent, round.
47. Male, apical marking (width/length): (1) absent, (2) broad (>1.3), (3) narrow (<1.3).
48. Female, ditto: (1) absent, (2) broad (>1.5), (3) narrow (<1.5).
49. Male, shape (length/width): (1) slender (>2.7), (2) intermediate (2.7-2.5), (3) stout (<2.5).
50. Female, ditto: (1) slender (>2.4), (2) intermediate (2.4-2.3), (3) stout (<2.3).
51. Pubescence: (1) with short and long hairs, (2) long haris.
52. Ditto, distribution: (1) dense, (2) sparse.
53. Male, elytral apex: (1) gently round, (2) subtruncate, (3) subacute ectoapically, (4) subacute endoapically.
54. Female, ditto: (1) gently round, (2) subtruncate, (3) subacute ectoapically, (4) subacute endoapically.
55. Elytral punctures on subbasal area: (1) strong, broader than interspace, (2) narrower than interspace.

(Leg)

56. Male, color of hind leg: (1) yellowish brown, (2) brown with balck patches.
57. Female, ditto: (1) yellowish brown, (2) black, (3) brown with black patches.
58. Hind femur: (1) not reaching elytral apex, (2) reaching elytral apex, (3) surpassing elytral apex.
59. Hing leg (femur/tibia): (1) slender (>0.95), (2) clavate (0.95-0.88), (3) strongly clavate (<0.88).
60. Spines of hind tibia: (1) straigth, (2) arcuate.
61. Spines of hind tibia: (1) unequal, (2) subequal.
62. Male, length of hend metatarsus to 2nd and 3rd combined: (1) longer, (2) shorter.
63. Female, ditto: (1) longer, (2) shorter.

(Abdomen)

64. Male, color: (1)black, (2) ochreous, (3) dark red.
65. Female, ditto:(1) black, (2) ochreous, (3) bicolor (black and red), (4) reddish black.
66. Male, apex of last sternite: (1) slightly emarginate, (2) bilobed, (3) subround.
67. Female, ditto: (1) subround, (2) evenly round.
68. Male, apex of last tergite: (1) subroundly truncate, (2) round, (3) emarginate.
69. Female, ditto: (1) round, (2) subtruncate with emargination, (3) round with emargination, (4) subtruncate.

(Male genitalia)

70. Aedeagus in lateral aspect (straight length/height): (1) very stroungly curved (<2.8), (2) strongly curved (2.8-4.0), (3) moderately curved (4.0-4.8), (4) slightly curved (>4.8).
71. Ditto, general shape (length/width): (1) short (<4.0), (2) slender (4-5), (3) long (5-6), (4) very long (>6).
72. Ditto, apical shape: (1) acutely pointed, (2)blunt.

73. Ditto, width to length at apical portion in lateral aspect: (1) slender (>2.8), (2) intermediate (2.8-1.8), (3) short (<1.3).
74. Ditto, length of distal half to width in lateral aspect: (1) long (>5), (2) intermediate (5-4), (3) short (4-3), (4) very short (<3).
75. Ditto, length to paramere in lateral aspect: (1) very long (>1.3), (2) slightly long (1.3-1.2), (3) similar (<1.2).
76. Ditto, length of distal half to proximal half in lateral aspect: (1) long (>1), (2) intermediate (1-0.8), (3) short (<0.8).
77. Apical lobe of paramere (length/width): (1) very long (>3), (2) long (3-2), (3) intermediate (2-1), (4) short (<1).
78. Ditto, inner margin: (1) convergent, (2) divergent.
79. Ditto, interspace batween apical lobes: (1) wider than apical lobe width, (2) slightly narrower than apical lobe width, (3) much narrower than apical lobe width.
80. Ditto, sensory pubescence: (1) long and short, (2) short.
81. Ditto, apex: (1) gradually narrowed, (2) strongly narrowed, (3) parallel-sided.

(Female genitalia)

82. Basal shape of spermatheca: (1) subroundly enlarged, (2) subtruncately enlarged, (3) gradually narrowed, (4) strikingly narrowed.
83. Ditto, apical shape:(1) gradully narrowed and curved, (2) strikingly narrowed and bent, (3) gradually enlarged, (4) strikingly enlarged.
84. Location of ejaculatory duct on spermatheca: (1) above left side, (2) below middle of left side, (3) right side.
85. Shape of stylus (length/width): (1) very long (>2.6), (2) long (2.6-2.3), (3) intermediate (2.3-2.0), (4) short (2.0-1.6), (5) very short (<1.6).
86. Apical segment of coxite (length/width): (1) very long (>3.0), (2) long (3.0-2.5), (3) intermediate (2.5-2.0), (4) short (2.0-1.5), (5) very short (<1.5).
87. Length of apical segment of coxite to stylus: (1) very long (>2.3), (2) long (2.3-2.0), (3) intermediate (2.0-1.5), (4) short (1.5-1.0), (5) very short (<1.0).

Table 3. The similarty measures and clustering methods used (measures between OTU x and y).

Coefficient	Clustering method
Jaccard similarity $JACCARD(x, y) = \frac{a}{a+b+c}$	Average linkage between groups (unweithted pair group method average) Average linkage within group Single linkage (nearest neighbour) Complete linkage (farthest neighbour)
Russell and Rao similarity $RR(x, y) = \frac{a}{a+b+c+d}$	Average linkage between groups (unweithted pair group method average) Average linkage within group Single linkage (nearest neighbour) Complete linkage (farthest neighbour)
Dice (Zekanowskii or Sorenson) similarity $Dice(x, y) = \frac{2a}{2a+b+c}$	Average linkage between groups (unweithted pair group method average) Average linkage within group Single linkage (nearest neighbour) Complete linkage (farthest neighbour)

Coefficient	Clustering method
Simple matching similarity $SM(x, y) = \frac{a+b}{a+b+c+d}$	Average linkage between groups (unweithted pair group method average) Average linkage within group Single linkage (nearest neighbour) Complete linkage (farthest neighbour)
Variance dissimilarity $VARIANCE(x, y) = \frac{b+c}{4(a+b+c+d)}$	Average linkage between groups (unweithted pair group method average) Average linkage within group Single linkage (nearest neighbour) Complete linkage (farthest neighbour)
Binary squared Euclidean distance $BSEUCLID(x, y) = b+c$	Centroid (UPGMC, unweighted pair group method centroid) Median (WPGMC, weighted pair group method centroid) Ward's method

Four binary matching similarity coefficients and 2 other binary dissimilarity coefficients were made through the FORTRAN which carried out an analysis using each binary data matrix by computing the information content of each character as well as the joint and mutual information content of all character pairs. For comparative survey on different methods for the same coefficient matirix to get a proper classification, 7 different clustering methods combined with 6 coefficient measures were conducted (Table 3).

RESULTS

A number of cluster analysis of Korean *Pidonia* was undertaken to show a better understanding of the relationships among the species of this genus. To compare the effect of using different similarity or dissimility coefficients as well as different clustering methods, 7 different clustering methods joined with 6 measures were carried out. Centroid, median and Ward's methods can only work with the binary squared Euclidean distance(Norusis, 1985; SPSS, 1988). The results achieved by each of this analysis are discussed as follows.

1. All characters

The most reliable way to classify the species of *Pidonia* was the use of the male genitalic characters intuitively. However, no critical attempt has ever been made to construct classifications derived separately from the genitalia, external characters, and the 2 sets of structures used together. Therefore, this analysis was attempted to show the effect on numerical classification of these 3 different suites of characters as a whole.

Analysis by Jaccard similarity measure

The picture showed that species of *Pidonia* s. str. in clustering distance are slightly farther than that given by the analysis using the binary data matrix including 'NC' (no comparison, cf. Dunn & Everitt, 1982). Except for that, in all methods the clustering positions and patterns among species closely coincided with those given by the analyses using the binary data matrix including 'NC' values. Apparently, *alpina*(3), *koreana*(8) and *alticollis*(4) consisted of a smaller group, the other species excluding *debilis*(1) and *puziloi*(2) consisted of a larger group. In all methods, *debilis*(1) and *puziloi*(2) isolated from each other. This is due to the fact that these species belong to the subgenera *Mumon*

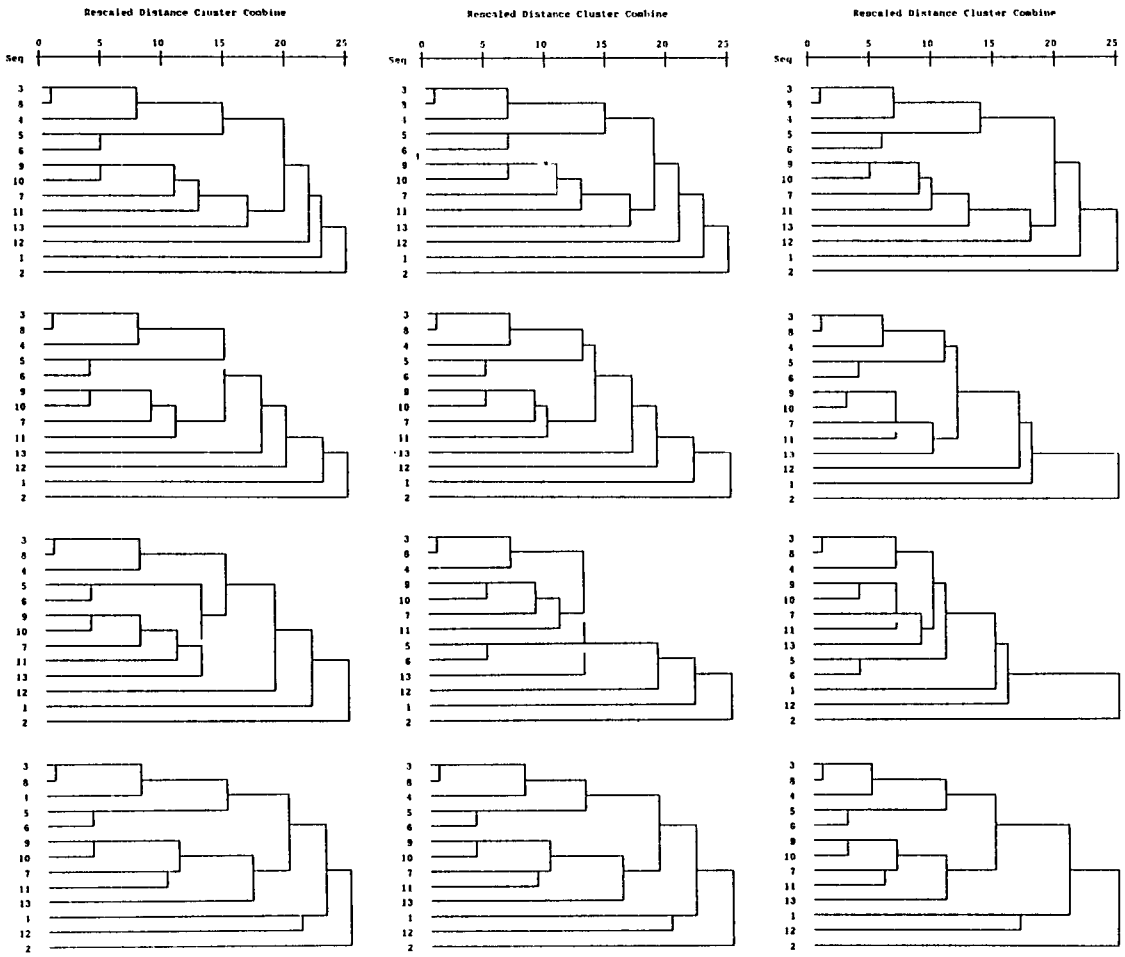

Fig. 2. a. General phenetic classification of Korean *Pidonia* based on the Jaccard similarity measure for the all characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the Russell & Rao similarity measure for the all characters (central: excluding 'NC' values, right: including 'NC' values; ditto).

Omphalodera respectively. In the complete linkage method, *similis*(12) was not clustered with those presumed conventionally to be the nearest relatives of *Pidonia* s. str. In all linkage methoads, *alpina* (3) and *koerana*(8) showed the highest similarity relationship (Fig. 2 a).

Analysis by Russell and Rao similarity measure

This analysis resulted in very similar to that of Jaccard measure except for the phenogram using the single linkage method. Especially, *amurensis*(5) and *elegans*(6) in the single linkage method were not clustered as in other linkage methods, and they were closely related to *suvorovi*(13). In the phenogram using the single linkage method, the clustering position of *similis*(12) exchanged for *debilis*(1) in comparison with that obtained by the analyses including 'NC' value (Fig. 2. b).

Analysis by dice similarity measure

The phenogram revealed by this analysis was very similar to that of Jaccard measure. The cluster distances in the groups usually showed slightly longer then those using the binary data matix including 'NC' value. Except for this, the clustering positions and patterns in all the species completely coincided with the analysis with 'NC' values. In all linkage methods, *weolseoae*(9), *longipennis*(10), *gibbicollis*(7), and *seungmoi*(11) clustered with those seemed conventionally to be the nearest relatives. However, *similis*(12) in the complete linkage method wes also quite isolated from its relatives belonging to *Pidonia* s. str. as above measures (Fig. 3. a).

Analysis by simple matching similarity measure

This analysis was nearly similar to those shown by the above measures. However, the phenogram using the average linkage within group method ignoed 'NC' values showed a slight difference in compared with other measures and methods. This clustered with those presumed traditionaly to be closely related species, such as *alticollis*(4), *amurensis*(5) and *gibbicollis*(7) group. On the other hand, in the phenogram using the complete linkage method including 'NC' values, the analysis resulted in 2 main clusters: one with *alpina*(3) to *seungmoi*(11); the other with *similis*(12) to *puziloi*(2). The latter was not clustered in accordance with the orthodox view. Moreover, *similis*(12) and *suvorovi*(13) clustered together with the ingredients belonging to other subgenera, which seemed not to be particularly related in the classical view. Except for this, the cluster placements and patterns in all the species accorded with the results by the same measure ignored 'NC' values, and by Jaccard measure (Fig. 3. b).

Analysis by variance dissimilarity measure

The results nearly crresponded to those by simple matching measure. In the pictures using average linkage between groups and single linkage methods, the clustering placements of *similis*(12) and *suvorovi*(13) exchanged each other in comparison with those obtained by the same method including 'NC' values. Except for this, the cluster placements and distances in all the members were nearly coincided with the results obtained by the same measure including 'NC' values. As in the phenograms

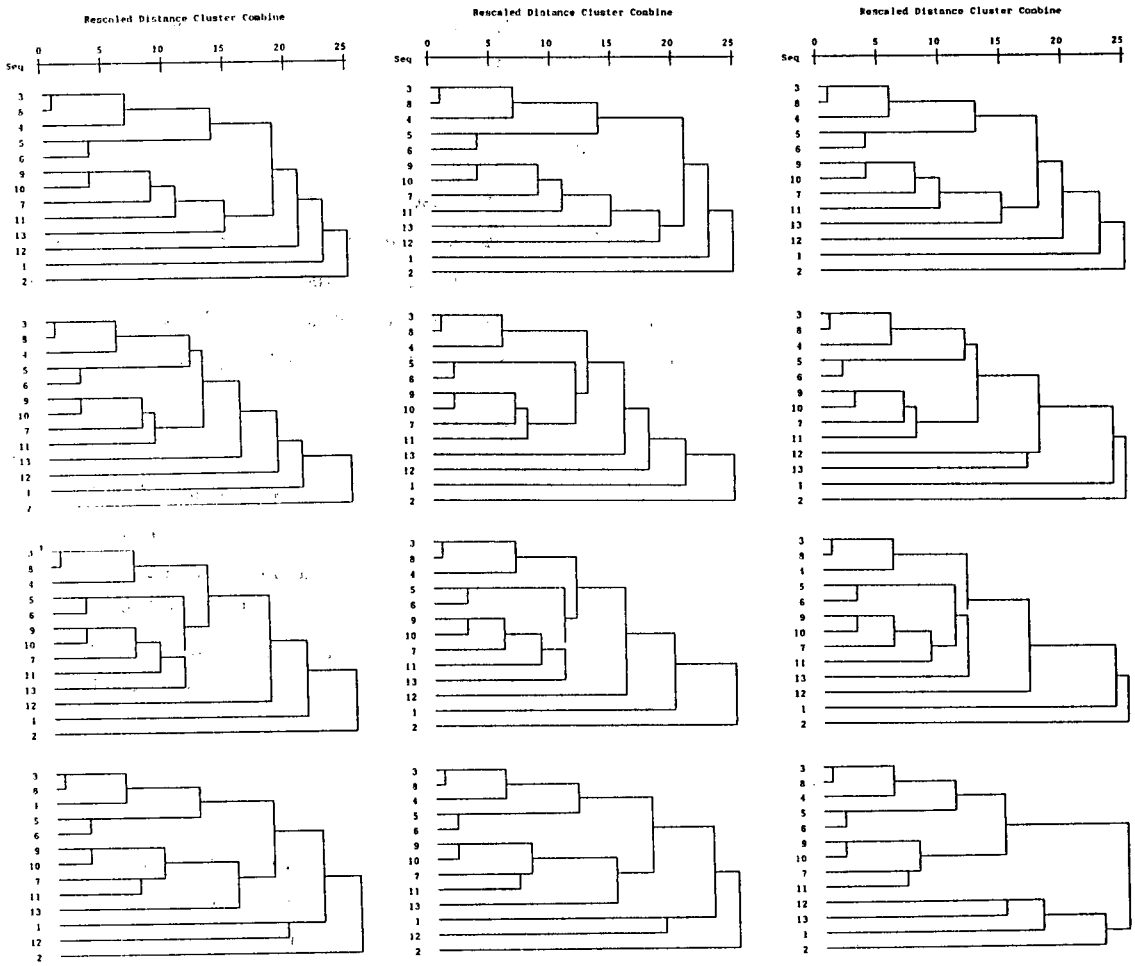

Fig. 3. a. General phenetic classification of Korean *Pidonia* based on the dice similarity measure for the all characters (left column: excluding 'NC' malues; 1st row: average linkage within troup, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the simple matching similarity measure for the all characters (central: excluding 'NC' values, right: including 'NC' values; ditto).

given by other measures, *similis*(12) was also isolated from its relatives which belong to *Pidonia* s. str. In the phenogram using the complete linkage method, *seungmoi*(11) clustered together with *gibbicollis*(7) which seemed to be related according to the traditional view. Generally all the species excluding *similis*(12) revealed their own relationships in accordance with orthodox views (Fig. 4. a).

Analysis by binary squared Euclidean distance measure

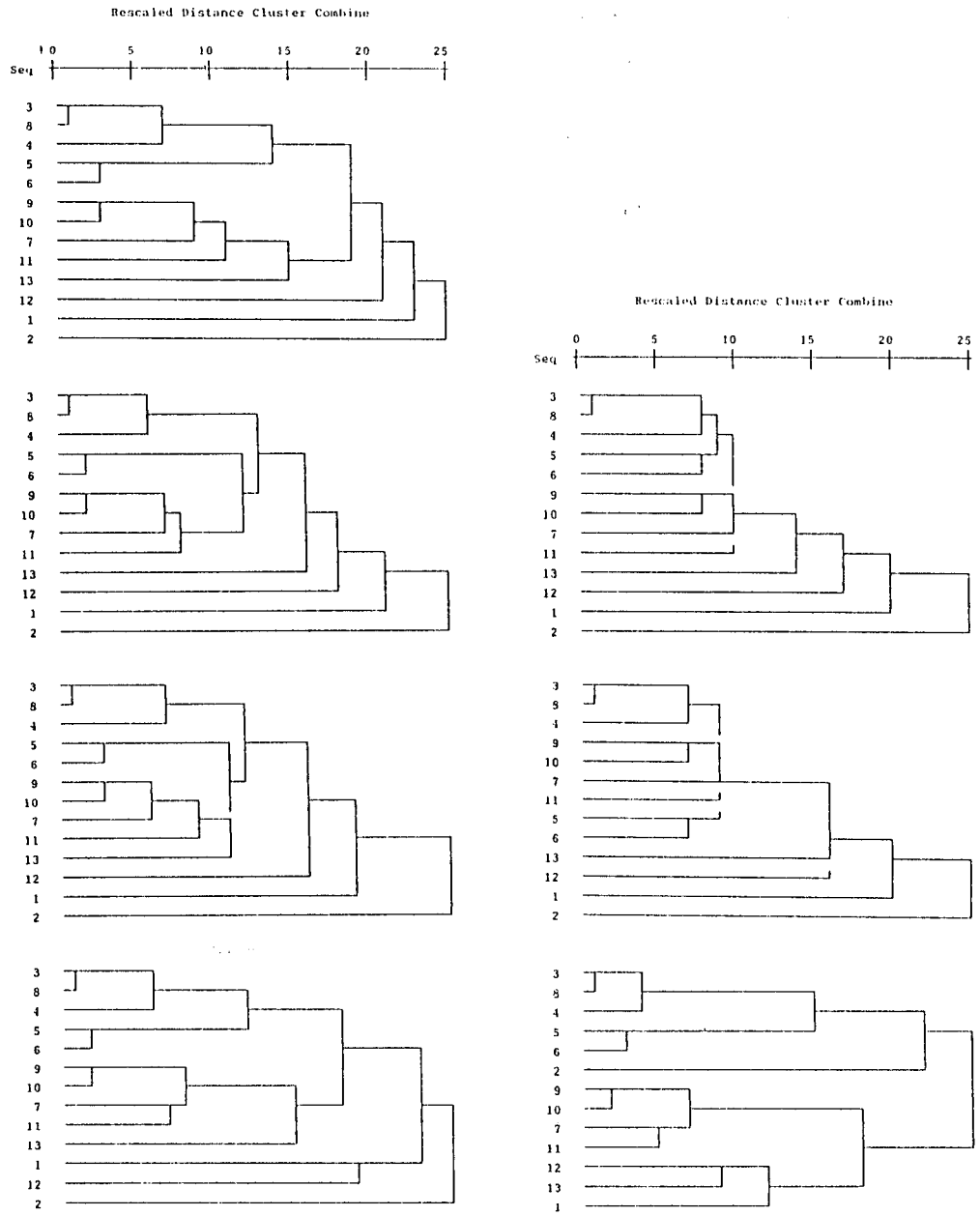

Fig. 4. a. General phenetic classification of Korean *Pidonia* based on the variance dissimilarity measure for the all characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the binary squared Euclidean distance for the all characters (right column: excluding 'NC' values; 1st: centroid method, 2nd: median method, 3rd: Ward's method).

Analysis by this measure was somewhat different from those shown by the above measure. This result completely coincided with that given by the same measure including 'NC' values. The cluster distances of all the species in Ward's method were shorter than those in both centroid and median methods. In the phenogram using the median method, each species placed to the expected subgroup satisfactorily as in the view of traditional taxonomy. However, in Ward's method, this analysis resulted in 2 main clusters: one with a smaller or intermediate group [*alpina*(3), *koreana*(8), *alticollis* (4), *amurensis*(5), elegans(6), *puziloi*(2)] blending ingredients of *Omphalodera* and *Pidoina* s. str.; the other with an intermediate or larger group incorporating both elements of *Pidonia* s. str. and *Mumon.* In the clustering patterns, *puziloi*(2) linked to the former branch (Fig. 4. b).

2. External characters

To reveal how much the placement of species by numerical methods using external characters alone accords with the traditional view, 7 clustering methods combined with 6 measures were carried out.

Analysis by Jaccard similarity measure

This analysis completely accorded with those obtained by the same measure including 'NC' values. The isolation of *similis*(12) and *suvorovi*(13) were not consistent with the views of the orthodox taxonomy, and thus it can be interpreted as a result of the over-emphasis to their conspicuous color patterns. Except for this, the general picture given by the phenogram seemed to be similar to traditional views. Moreover, most species clustered in accordance with the phenograms based on the all characters (external + genitalic characters). In the phenogram using the single linkage method, *amurensis* (5) and *elegans*(6) were not corresponded to those using other methods. In the phenograms using either average linkage between groups or complete linkage method, *suvorovi*(13) nearly clustered together with *debilis*(1), which may be due to the emphasis on colors as the former is entirely black and the latter entirely fulvous (Fig. 5. a)

Analysis by Russell and Rao similarity measure

As in the case of the previous analysis, *alpina*(3) and *koreana*(8) also showed the nearest similarity relationship, whereas *puziloi*(2) represented the farthest similarity. In the phenograms using all methods, *amurensis*(5) and *elegans*(6) clustered together into the first branch except for that obtained by the single linkage method including 'NC' values. The picture using the average linkage between groups method was consistent with that using same method including 'NC' values. In the phenograms using all methods, *suvorovi*(13) clustered with *debilis*(1). This may be owing to the color pattern (Fig. 5. b).

Analysis by dice similarity measure

The phenograms closely corresponded to those by the same measure including 'NC' values and by Jaccard measure except for difference of the cluster distances in all the species. The clustering ranks

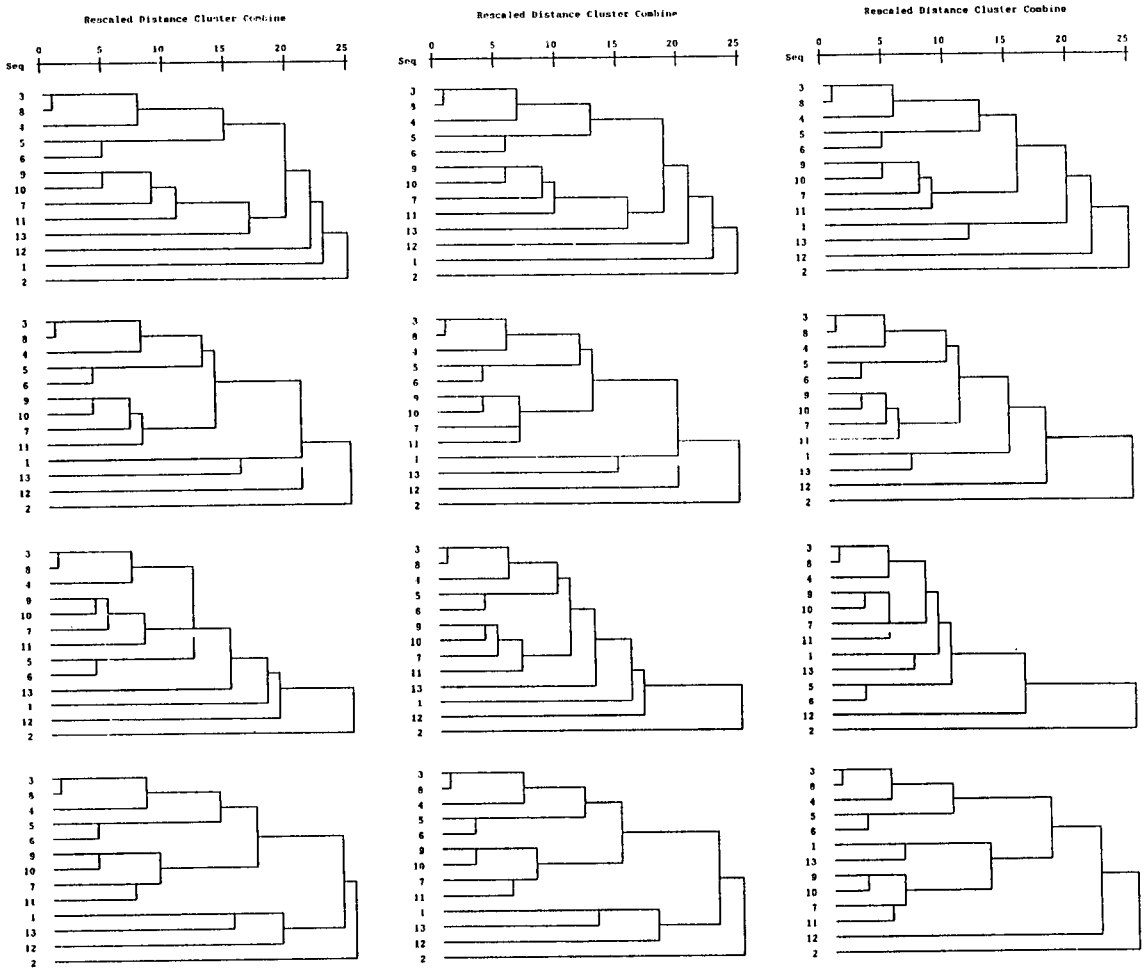

Fig. 5. a. General phenetic classification of Korean *Pidonia* based on the Jaccard similarity measure for the external characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the Russell & Rao similarity measure for the external characters (central column: excluding 'NC' values, right: including 'NC' values; ditto).

of *amurensis*(5) and *elegans* (6) in the single linkage were not consistent with those in other methods. Especially in the phenogram using the complete linkage method, *suvorovi* (13) and *similis*(12) clustered together with *debilis*(1), subgenus *Mumon*, seemed not to be particularly related in the classical views. This can be interpreted as a result of the over-emphasis to their conspicuous color patterens. Except for this, the general pictures seemed to be in accordance with the traditional taxonomic views (Fig. 6. a).

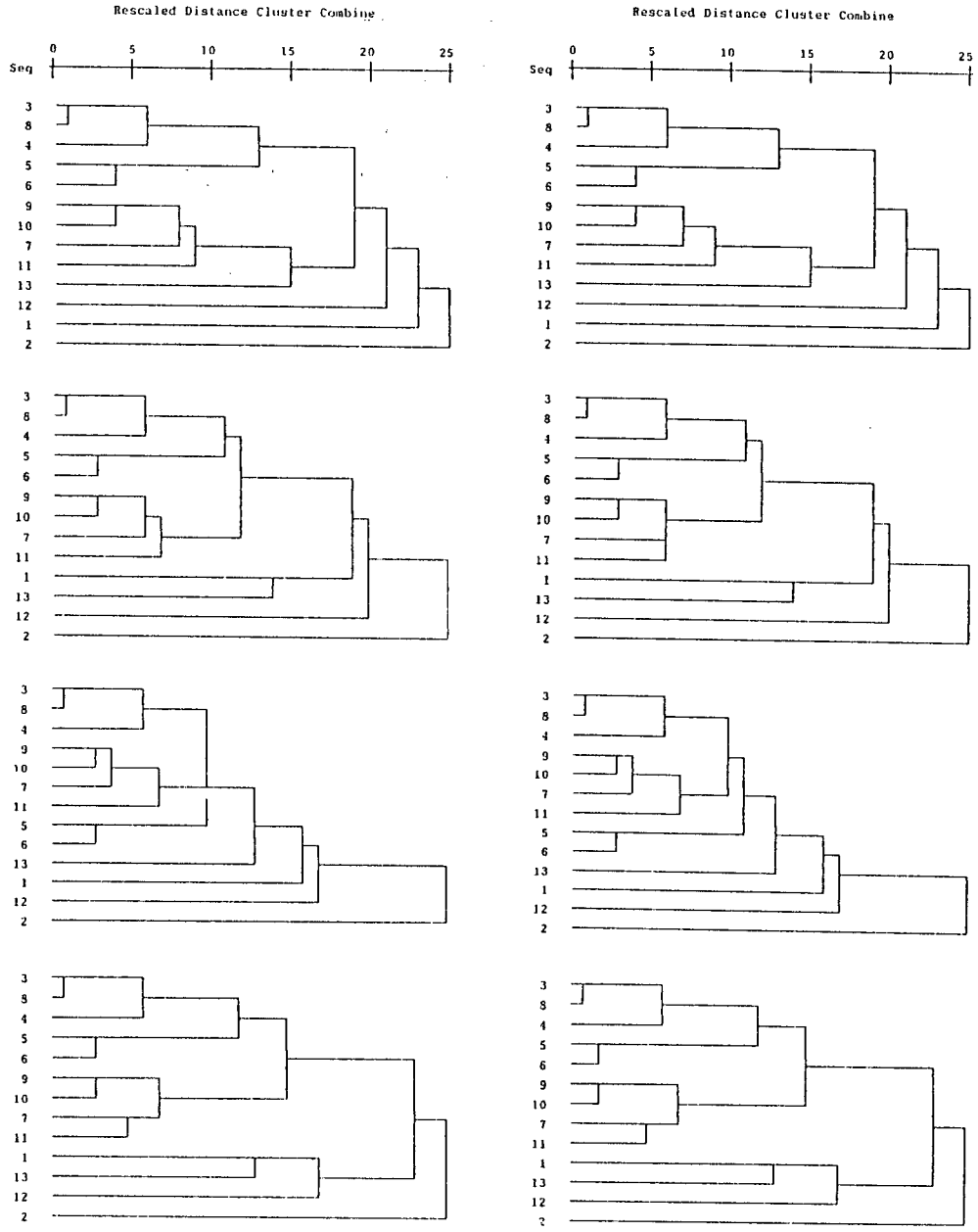

Fig. 6. a. General phenetic classification of Korean *Pidonia* based on the dice similarity measure for the (left column: external characters excluding 'NC' valuse; 1st row: average linkage within group, 2nd : average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the simple matching similarity measure for the external characters (right: excluding 'NC' values; ditto).

Analysis by simple matching similarity measure

The pictures generally accorded with those by Jaccard measure except for clustering distance of *gibbicollis*(7) and *seungmoi*(11) by the average linkage between groups method ignored 'NC' values. In comparison with the results by the same measure including 'NC' values, the phenograms given by the complete linkage method accorded with each other. However, the clustering ranks of some species were not consistent with those in the same methods. This analysis resulted in 2 main clusters besides result by the single linkage method ingnored 'NC' values: the first group with *alpina*(3), *koreana*(8), *alticollis*(4), *amurensis*(5), and *elegans*(6); the other with the remainder species. This seemed to be particularly related to the effect of body size and color pattern. In spite of the *Pidonia* s. str., *suvorovi* (13) in the phenograms using both average linkage between groups and complete linkage methods clustered with *debilis*(1), thus it seemed not to be particularly related to the classical taxonomic views. This may be due to the unique clolr of elytra (Fig. 6. b).

Analysis by variance dissimilarity measure

The phenograms closely accorded with those by jaccard measure. However, the cluster distances of all the species were slightly shorter. In comparison with results by the same measure with 'NC' values, the cluster ranks in the some species disaccorded with each other except for those by the complete linkage method. In general, the species belonging to *Pidonia* s. str. mede up 2 subgroups by the method of average linkage within group. This result is well consistent with the traditional taxonomic views. However, *similis*(12) joined with neither groups. The psositions of *amurensis*(5) and *elegans* (6) in the single linkage method independently located from each other in contrast with those depicted in other methods. The placement of *puziloi*(2) is quite isolated from other species, and it can be referable that the result corresponds well to the classical taxonomic views. As in the case of the previous analysis, *alpina*(3) joined with *koreana*(8) which presumed conventionally to be the nearest relative (Fig. 7. a).

Analysis by binary squared Euclidian distance measure

The pictures completely coincided with those given by the same measure with 'NC' values. This analysis resulted in 2 main clusters: on group consisting of *suvorovi*(13), *similis*(12), *debilis*(1), and *puziloi*(2); the other group with the remainder species. The group comprising *alpina*(3) to *seungmoi* (11), in the pictures given by Ward's method, was divided into 2 subgroups: the first incuding *alpina* (3) to *elegans*(6), and the other holding *weolseoae*(9) to *seungmoi*(11). The latter joined again with those seemed conventionally to be the nearest relatives, such as *alpina*(3) or *koreana*(8). The placements of *similis*(12) and *suvorovi*(13) revealed inconsistently in different clustering methods. However, the species belonging to *Pidonia* s. str. linked into the seme group (Fig. 7. b).

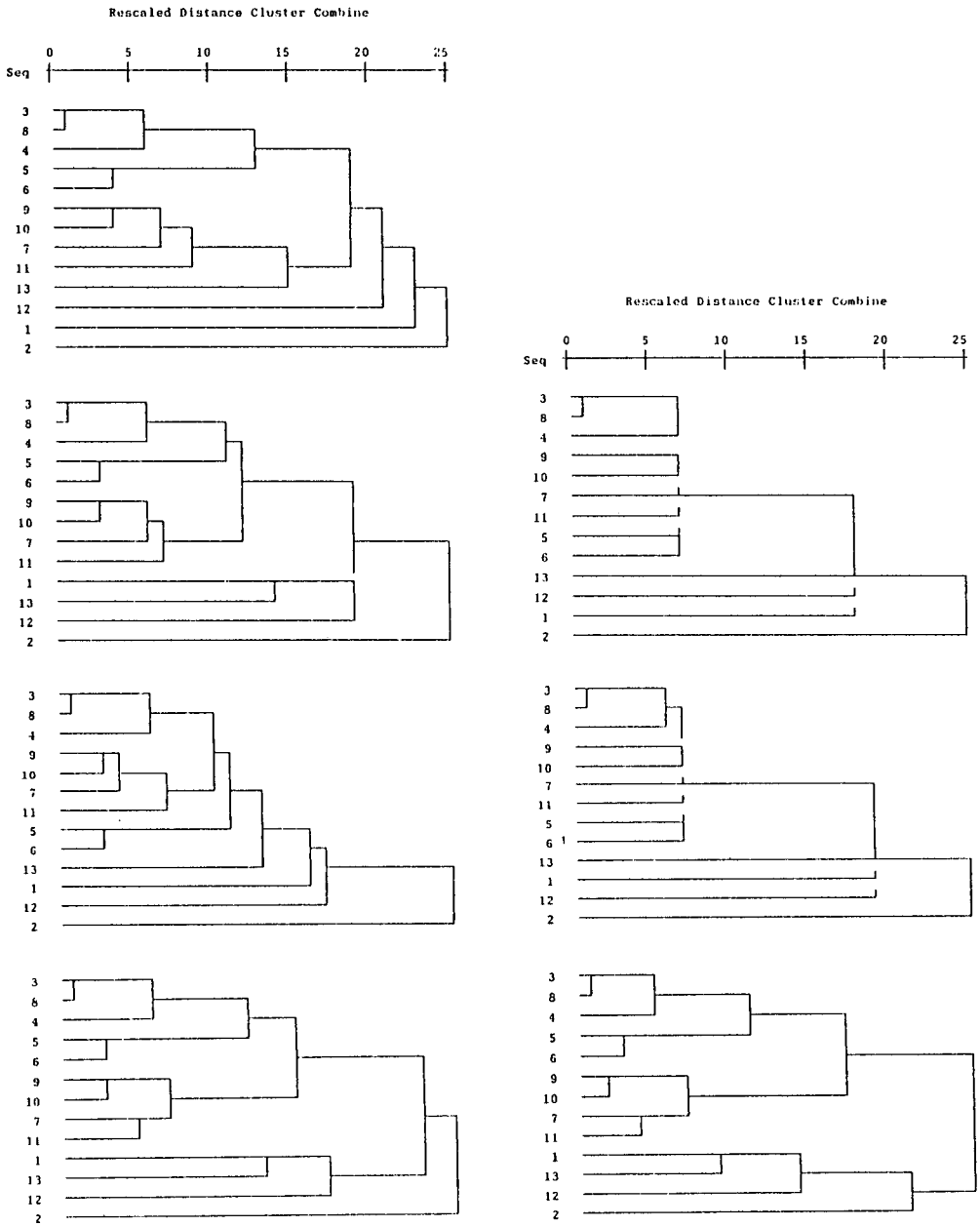

Fig. 7. a. General phenetic classification of Korean a *Pidonia* based on the variance dissimilarity measure for the external characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the binary squared Euclidean distance for the external characters (right: excluding 'NC' values; 1st: centroid method, 2nd: median method, 3rd: Ward's method).

3. Genitalic characters

Analysis by Jaccard similarity measure

This results somewhat disaccorded with those based on both all and external characters, and those gained by the same measure with 'NC' values. However, the phenograms using the single linkage and complete linkage methods were consistent with those given by the same methods with 'NC' values. In the comparison with results in the same measures for all and external characters, the similarities of *amurensis*(5) in relation to *elegans*(6), and *weolseoae*(9) to *longipennis*(10) accorded well with the results discussed above. However, in the phenogram using the average linkage within groups, *gibbicollis*(7) clustered with the first branch in contrast with those resulted from the other methods. In the phenogram using the single linkage method, *alticollis*(4) was not clustered with those seemed conventionally to be the nearest relatives, such as *alpina*(3) or *koreana*(8). Whereas *similis*(12) and *suvorovi*(13) custered differntly according to the clustering methods. However, all the species belonging the *Pidonia* s. str. linked together with the same subgenus group in compared with those using both all and external characters. In the phenogram using the average linkage within group method, only the positions of *gibbicollis*(7), *similis*(12) and *seungmoi*(11) mutually replaced to *similis*(12), *seungmoi*(11) and *gibbicollis*(17) each other in the same method with 'NC' values. In comparision with the picture using the average linkage between groups method, only *similis*(12) clustered with *alticollis* (4) group in the same method with 'NC' values (Fig. 8. a).

Analysis by Russel and Rao similarty measure

This phenongrams disaccorded with those based on both all and external characters, and those given by the same measure with 'NC' values. Except for the phenogram yielded by the complete linkage, this results also did't correspond to those based on the Jaccard similarity for the genitalic characters. In the phenogram using the average linkage within group method, only *similis*(12) and *gibbicollis* (7) mutually replaced each other in the analysis by Jaccard measure. In the average linkage within group and between groups methods, *similis*(12) was not joined in accodance with the traditional view. In the single linkage, some species were not clustered with those presumed in the classical views: such as *suvorovi*(13) in relation to *gibbicollis*(7). Moreover, *seungmoi*(11) was not clustered with the group belonging to *Pidonia* s. str., and incorporated with *puziloi*(2) which belongs to the subgenus *Omphalodera*. This analysis therefore produced rather poor results, showing a partial confusion of the recognzed subgenera. Each branch comprised pairs of species, which clustered similar to those of the orthodox views. In the average linkage within group method, *gibbicollis*(7) isolated from the other species, the species clustered with *suvorovi*(13) in the same method with 'NC' values. The other phenograms dissaccorded with those gained by the same methods with 'NC' values, such as cluster ranks, cluster distances etc. in some species (Fig. 8. b).

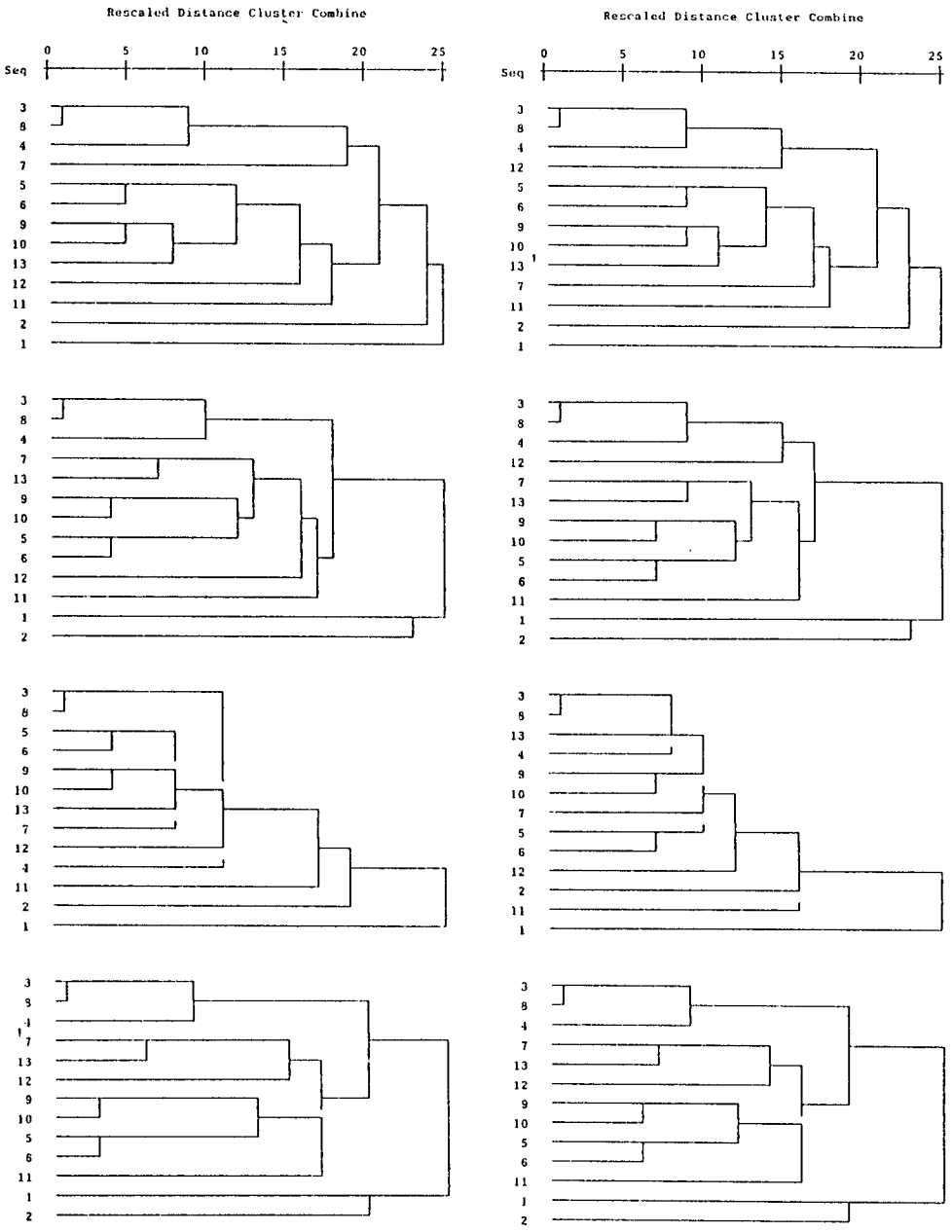

Fig. 8. a. General phenetic classification of Korean *Pidonia* based on the Jaccard similarity measure for the genitalic characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the Russell & Rao similarity measure for the genitalic characters (right: excluding 'NC' values;ditto).

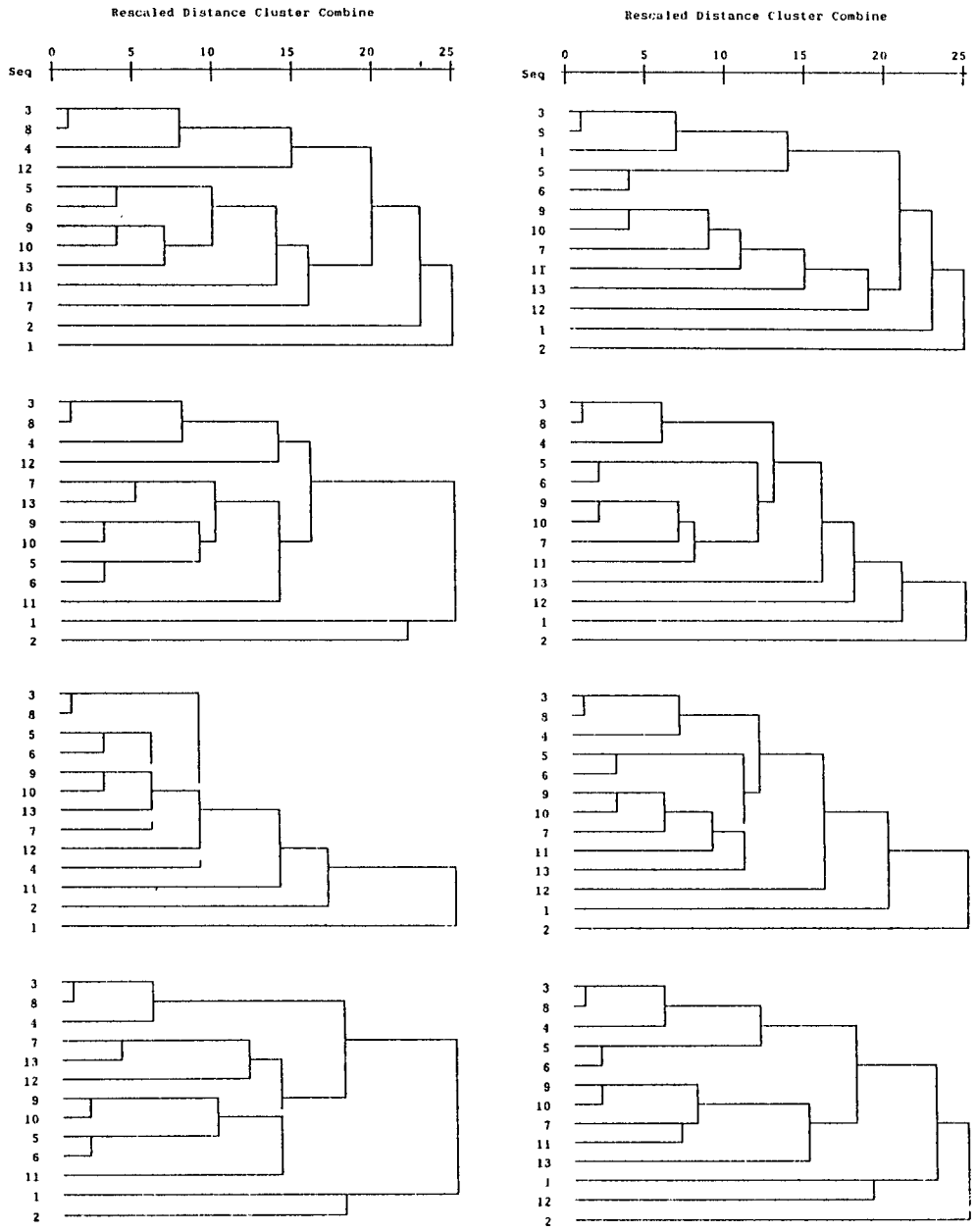

Fig. 9. a. General phenetic classification of Korean *Pidonia* based on the dice similarity measure for the genitalic characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the simple matching similarity measure for the genitalic characters (right: excluding 'NC' values; ditto).

Analysis by dice similarity measure

This results were also somewhat different from those based on both all and external characters. Whereas, the phenograms except for the cluster distances of all the species slightly longer than them, completely accorded with those in the same measure with 'NC' values, and the Jaccard measure for the genitalic characters. This analysis resulted in 3 main groups, which represented well the subgenera *Pidonia* s. str., *Mumon*, and *Omphalodera*. In the phenograms using both average linkage within group and between groups methods, *similis*(12) was not clustered in accordance with the traditional taxonomic views. And *alticollis*(4) in the single linkage method was also not linked to the expected place. The phenogram using the complete linkage method was a rather satisfactory clustering under the classical taxonomic views. This is closely similar to the pictures given by the same method in Jaccard, and Russell and Rao measures (Fig. 9. a).

Analysis by simple matching similarity measure

This results nearly accorded with those based on both all and external characters, and those yielded by the same measure with 'NC' values, besides cluster placements in some species. Also, the pheongrams disaccorded with those by Jaccard measure for the genitalic characters. In comparison with results in the same methods with 'NC' values, *suvorovi*(13) in the average linkage between groups and complete linkage methods clustered with *similis*(12). This analysis using the average likage between groups method resulted in 2 main clusters too: one with *alpina*(3) to *alticollis*(4); the other with *amurensis*(5) to *seungmoi*(11). However, *suvorovi*(13) and *similis*(12) were not joined with the species belonging to *Pidonia* s. str. The phenogram using the single linkage method was well accorded with the traditional taxonmic views. However, *similis*(12) in the complete linkage method joined with *debilis*(1) which belongs to the subgenus *Mumon* (Fig. 9. b).

Analysis by variance dissimilarity measure

This phenogram also somewhat disaccorded with those based on both all and exteral characters, and those gained by the same measure including 'NC' values. In the phenogram using the average linkage within group method, *smilis*(12) instead of *gibbicollis*(7) linked together with the group comprising *alpina*(3) to *alticollis*(4) in comparison with those by the same method of Jaccard measure. The phenograms using the average linkage between groups and complete linkage methods nearly accorded with those by the same method of Jaccard measure. However, *seungmoi*(11) in the single linkage method was not joined with the group beloging to *Picdonia* s. str. In the complete linkage method, the analysis resulted in 3 main clusters which well accorded with the traditional taxonmic views. *Pidonia* s. str. consisted of 2 branches; one group including *alpina*(3) to *altiollis*(4), and the second with *gibbicollis*(7) to *seungmoi*(11). In the former group, *alpina*(3) and *koreana*(8) made a subgroup of closely related species. Among the second branch, *gibbicollis*(7), *suvorovi*(13), *weolseoae*(9), *longipennis*(10), *amurensis*(5), and *elegans*(6) reasonably clustered according to the othodox views. The position of *puziloi*(2) which belongs to *Omphalodera* showed nearer relationship to *debilis*(1)

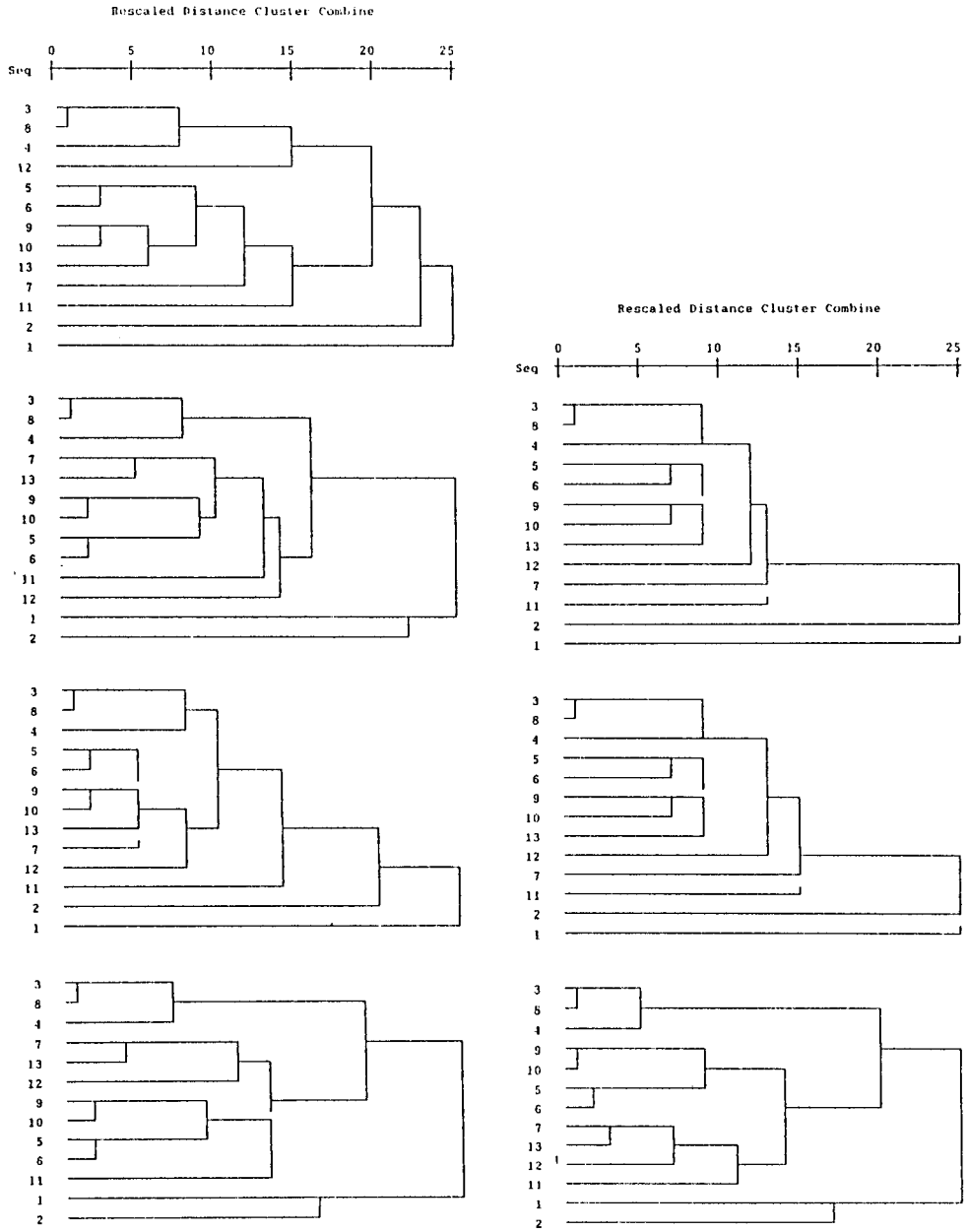

Fig. 10. a. General phenetic classification of Korean *Pidonia* based on the variance dissimilarity measure for the genitalic characters (left column: excluding 'NC' values; 1st row: average linkage within group, 2nd: average linkage between groups, 3rd: single linkage, 4th: complete linkage).

b. General phenetic classification of Korean *Pidonia* based on the binary squared Euclidean distance for the genitalic characters (right: excluding 'NC' values; 1st: centroid method, 2nd: median method, 3rd: Ward's method).

which belongs to *Mumon* as implied by the picture. However, this result was not agreed with the orthodox views (Fig. 10. a).

Analysis by binary squared Euclidean distance measure

This results also disaccorded with those in the same measure for the all and external characters. However, the pictures completely accorded with those of the same measure including 'NC' values. Moreover, the phenograms using the centroid methods with and without 'NC' values also completely coincided with those using median method respectively. This analysis well represented by 3 subgenera: *Pidonia* s. str. with *alpina*(3) to *seungmoi*(11), *Omphalodera* with *puziloi*(2), and *Mumon* with *debilis*(1). The placements of *gibbicollis*(7) and *seungmoi*(12) in the centroid method were rather isolated from *suvorovi*(12) which seemed to be related according to the traditional views. In Ward's method, this analysis also resulted in 3 main groups: the first group with *alpina*(3) to *alticollis*(4), the second with *weolseoae*(9) to *seungmoi*(11), and the third incorporating *debilis*(1) to *puziloi*(2). The group including *debilis*(1) and *puziloi*(2) was not in agreement with the classical taxonomic views. As in the case of the previous analysis, *weolseoae*(9) closely joined with *longipennis*(10) on the basis of the general shape of aedeagus and paramere. Among the first, all the species consisted of a satisfactory clustering under the traditional views, as they have short sensory pubescence on the apex of paramere, and of similar shape in the aedeagus (Fig. 10 b).

CONCLUSION

In general, there were scarcely differences among the clustering groups represented by each measure. However, the phenograms using the measures including joint absences (Value d) slightly differed from those using the measures excluding joint absences.

As discussed above, the results of Russell and Rao measure nearly accorded with those of the simple matching, and the results of Jaccard with those of the dice, respectively. The joint absences in denominator seemed to infulence the relationship pattern of *Pidonia*.

The clustering distances in each measure using the binary data matrix including 'NC' values were slightly shorter than those excuding 'NC' values. And neither the phenograms by Russell and Rao nor simple matching measure were in accordance with some clusters of those reprsented by the same measures excluding 'NC' values.

Especially, the phenograms using the complete linkage method did not correspond to those yielded by the same method excluding 'NC' values.

In the analysis based on all the characters using the binary data matrix including, or excluding 'NC' values, the results completely accorded regardless of measures or methods. The phenograms using both centroid and median methods seemed to be accord with the traditional taxonomic views. In the analysis based on the external characters using the same measures and methods, the results were not a satisfactory clustering under the classical taxonomic views. Finally, in the analysis based on the

genitalic characters alone using the identical measures and methods, the clusters among species are well accordance with the traditional taxonomic views. In the phenetic analyses of the genus *Pidonia* using the above 7 methods and 6 measures, the general pictures given by the phenograms seemed to be nearly accorded with the traditional taxonomic views.

The placements of *debilis* (1) and *puziloi* (2) were usually isolated from the species of *Pidonia* s. str., and joined with the species which belong to the subgenera *Mumon* and *Omphalodera* respectively. Such pairs or groups of species as *alpina* (3), *koreana* (8), *alticollis* (4), *amurensis* (5), *elegans* (6), *weolseoae* (9), and *longipennis* (10) seemed to be so closely related to each other. The clustering patterns of *similis* (12) and *suvorovi* (13) in the analysis of both all and external characters were not linked to the group which belong to same subgenus. However, the species in the analysis based on the genitalic characters showed a satisfactory clustering in the classical taxonomic views.

On the whole, the phenograms summarized well the relationships between these species, confirmed the subgenera recognized by the traditional taxonomic views, and thus contributed to a better understanding of the relationships among the species of this genus.

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韓國產 각시하늘소屬의 數理分類(딱정벌레目: 하늘소科)

安承樂[1] · 權容正[2]

[1] 國立中央科學館 自然史硏究室
[2] 慶北大學校 農科大學 農生物學科

우리나라산 각시하늘소속에 대한 표현론적 수리분류방식과 경험적 전통분류방식의 차이 및 각종 수리결합방법에 따른 영향등을 평가하기 위하여 총 87유형별 260형질을 선정, 집괴분석을 시도하였다. 그 결과, 생식기형질의 비교분석에서 전통분류와 가장 유사하였으며, 각 분류군의 상관관계를 이해하는데 도움을 주었다.

검색어: 수리분류, 표현론, 딱정벌레목, 하늘소과, 각시하늘소속

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